AN EVALUATION OF A CURRENT REAR IMPACT DUMMY AGAINST HUMAN RESPONSE CORRIDORS IN BOTH PURE AND OBLIQUE REAR IMPACT

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ABSTRACT

Much recent research has been conducted on Whiplash Injury, however little has focussed on oblique or non-symmetrical rear impact loading and the attributes that a test device should have to detect injury risk, including responses to asymmetrical loading, which will be needed in a regulatory test device. A series of low speed, oblique rear tests have been conducted with volunteers and the RID^{3D} dummy. Pure rear impact tests were also conducted with the RID^{3D} to replicate previous tests using volunteers as well as the BioRIDIIb and THORα dummies. The paper also reviews further issues that must be addressed for regulatory application.

This research evaluated:

- Volunteer responses with respect to impact orientation and muscle activity
- The RID^{3D}'s response against volunteer response corridors for oblique rear impact.
- The RID^{3D} for repeatability and reproducibility.
- The RID^{3D}, BioRIDIIb and THORα dummy responses against human response corridors for pure rear impact.
- The interaction of the dummy with the test seat compared to human subjects.

The main findings were:

- Muscle activity should be considered in rear impact events.
- Both RID^{3D} and BioRIDIIb had aspects of their responses which fitted the human response corridors generated.
- The THORα's response was less human-like than the other two dummies.
- Both RID^{3D} and BioRIDIIb had aspects of their motion which could be improved.
- There were issues of concern with the RID^{3D} in terms of reproducibility.
- The BioRIDIIb was the only dummy that interacted with the test seat in a human like way
- The BioRIDIIb appeared to be the more biofidelic dummy based on the testing conducted but further study of the reproducibility of its response is required.

INTRODUCTION

Extensive research has been carried out during the last 10 years in the area of rear impact and whiplash injury research, resulting in the development of two dummies designed specifically for rear impact testing. The first, the BioRID II, was developed by Davidsson (2000) [1] with a fully articulated spine, designed to be representative of a human seated in a typical vehicle seat. The RID^{3D} started life as the RID (Svensson and Lovsund, 1993 [2]) and then the TRID neck (Thunnissen et al, 1996 [3]), designed as an adaptation for the Hybrid III dummy. However, as a result of the EC 4th Framework project – 'Whiplash I' project the neck was applied to a modified THOR torso, which also included a modified pelvis and abdominal flesh, creating the RID2. The neck was then modified in the Whiplash II project to detect whiplash injuries from all impact directions to create the RID^{3D}.

The BioRID has been evaluated against the RID2 by Zellmer et al (2002) [4], who concluded that in terms of seat ranking ability using injury criteria such as NIC, the two dummies were comparable. The authors used a recently designed dynamic sled-based test procedure, a range of different car seats and NIC and Nkm for injury criteria to compare the two dummies. The designs of the two dummies were discussed in detail. Zellmer et al noted that although the results were comparable the kinematics of the two devices were different. The authors recommended that the kinematics of each dummy should be compared with those of human volunteers to determine whether particular aspects of human motion are important and to show which dummy was the most "human-like". The authors do not appear to have evaluated the repeatability or reproducibility of either dummy during their test series.

A wide variety of volunteer and PMHS tests have been conducted by different research groups to generate biofidelity data for the evaluation of rear impact test devices and in order to gain an understanding of the mechanisms and subtleties of Whiplash injury. However, to date, all biofidelity data against which dummies have been evaluated has been generated from pure rear impacts. Golinski and Gentle (2002) [5] used a model of the Hybrid III dummy with a human neck to show that a scenario where the occupant had their head turned at an angle just prior to impact could significantly increase the stress on the neck. As part of the

Whiplash II project, TRL set out to generate high quality oblique-rear impact volunteer response data, as reported by Willis et al (2004) [6]. These tests followed on from work conducted by Roberts et al (2002) [7] to generate high-quality pure rear volunteer response data. Both test series used identical test set-ups and evaluation techniques so that the two sets of data would be comparable and any significant differences in volunteer response could be identified. The only difference between the two test series was that the volunteers used for the oblique-rear tests were blindfolded and given mental tasks to complete which were played through headphones to ensure that the volunteers were unaware of the impending impact and were therefore unbraced.

In order to make best use of these response corridors, a variety of dummies were evaluated against the pure rear response corridors (Roberts et al, 2002 [7]). Subsequently the RID^{3D} was evaluated against both sets of response corridors. In order to make the evaluation more thorough, two identical prototype RID^{3D}s were tested under identical impact conditions, in order to assess the reproducibility and repeatability of the dummy as well as its biofidelity. The results of the pure rear tests with the RID^{3D} may be compared to those of other dummies and provide a basic comparison between the RID^{3D} and BioRIDIIb. (It should be noted that the BioRID is at revision IIg at time of writing.)

METHOD

The test procedure used for the volunteers was documented by Willis et al (2004) [6]. The testing was conducted under strict ethical guidelines and approval was obtained from the relevant medical ethics committee before testing commenced. A group of eight male volunteers, approximately 50th percentile, were tested in an oblique rear impact scenario, using a dual sled system to give an impact of 2g and a ΔV of 7kph (1.9m/s). The seat used was angled at 15° to the direction of impact as it was thought that having the volunteers' heads turned at an angle would have carried too great a risk of injury and could not have been replicated with a dummy. The angle of 15° was based on a study of drivers in a range of vehicles and the angle through which they turned their heads to monitor the mirrors etc. The volunteers were blindfolded and given a series of mental and oral tasks so that they were unaware of the impending impact. The volunteers were instrumented with accelerometers, visual targets and electromyography (EMG) sensors.

The dummy tests were designed to apply identical impact conditions to the dummy as had been used for the volunteers. The oblique rear set-up is illustrated in Figure 1 (the pure rear set-up was identical but with the seat facing forwards). Two identical prototype RID^{3D}s were tested under both pure and oblique rear impact conditions, using two impact pulses as illustrated in Figure 2, the first was used for the volunteers, the second was a more severe pulse to assess the dummy's sensitivity. The test seat was based on an UN/ECE Regulation 44 (1998) Test Bench but the seat back was padded with 70mm polyethylene foam and increased to a height of 590mm above the CR line. An adjustable head restraint was also added. The seat back and head restraint were instrumented with load cells and inertial compensation accelerometers, as illustrated in Figure 3. A pressure mat was positioned 50mm from the base of the seat back to record the pressure distribution formed by each subject's back against the seat during the test. The dummy was instrumented with a variety of internal sensors; tri-axial accelerometers at the head centre of gravity, T1, T12 and Pelvis; 6-axis upper and lower neck load cells and tilt sensors as illustrated in Figure 5. In addition the dummy was instrumented with external tri-axial accelerometers on the left and right of the head, at T1 and on the chest to mimic the positions used for the volunteer instrumentation.

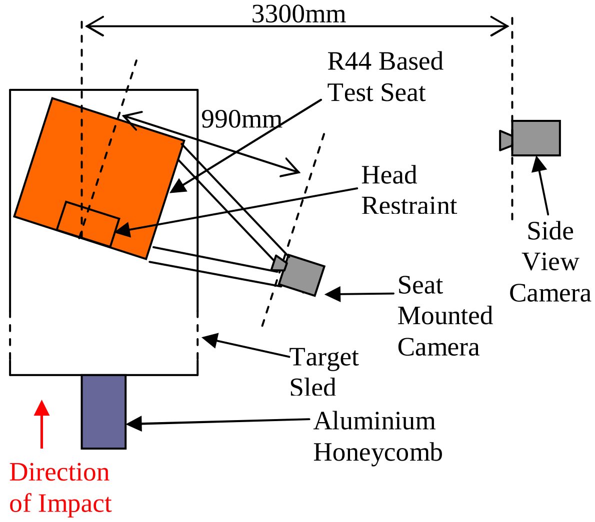


Figure 1: Oblique-Rear Impact Test Set-up as viewed from above

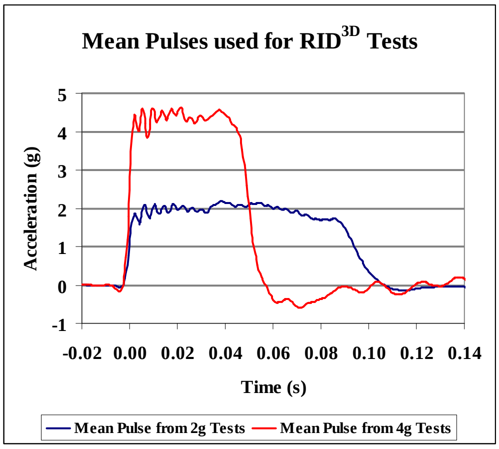


Figure 2: Acceleration Pulses used for RID^{3D} Testing

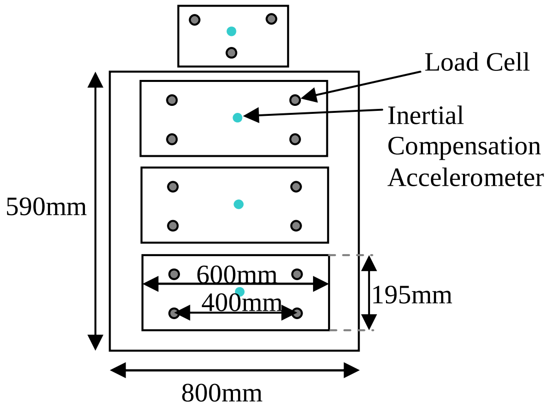


Figure 3: Seat Back Instrumentation

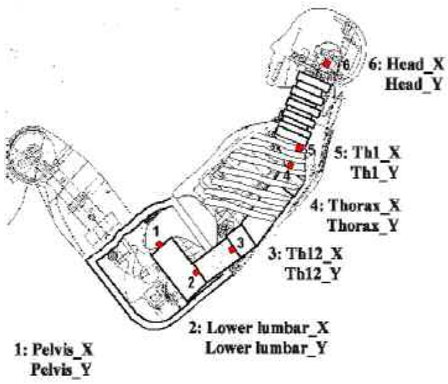


Figure 4: RID^{3D} Tilt Sensor Positions

Position of Sensor	Set-up Angle Target and Tolerance	
	x-axis	y-axis
Head	$0^{o} \pm 1°$	0^{o} + $0^{o}/-1°$
T1	None	$0^{o} \pm 1°$
Thorax	None	None
T12	None	None
Pelvis	$0^{o} \pm 1°$	$22.5^{o} \pm 5°$
Lumbar Spine	None	$0^{o} \pm 1°$

Figure 5: RID^{3D} Settings for Tilt Sensors

A standard procedure was followed for dummy positioning to try to ensure repeatability. Although, initially, the procedure demonstrated in training (for the RID^{3D}) was followed to set the lumbar bracket and T1 bracket correctly, these settings were not altered for a given dummy during testing, to try to ensure that the dummy was set up as repeatably as possible. The dummy positioning procedure (once lumbar and T1 brackets were set) was as follows:

- External sensors and tracking targets were put in place.
- The dummy back flesh was put in place
- The neck cable tension was checked qualitatively (no quantitative method was available)
- The dummy was positioned such that the back-set[1] was 75mm (a spacer was used for this) and all tilt sensors were reading within the set-up range as far as this was possible.
- Stills photographs were taken and the position of visual targets on the dummy were noted, relative to the sled.
- Post-test, more photographs were taken. The dummy back flesh was removed to ensure that it did not become compressed between tests. The dummy was also inspected for damage.

RESULTS

Oblique Rear Volunteer Tests

High quality response corridors were generated from the volunteer testing and these have been previously presented by Willis et al 2004 [6]. It was noted that although the amount of displacement and acceleration recorded varied between different volunteers, their responses usually had similar characteristics, for a given parameter. Thus the displacement and acceleration corridors represented the characteristics of the volunteer responses well.

When the oblique rear volunteer results were compared to the results of the pure rear tests conducted by Roberts et al 2002, it was found that:

- The oblique rear volunteers were much less aware of the timing of the impending impact and therefore were unprepared for the impact,

[1] Back-set – the distance between the rear of the head and the front of the head restraint.

whilst the pure rear volunteers were aware and to some extent “braced” themselves.

- The oblique rear volunteers experienced head rotation about the z-axis and some lateral motion. This was not recorded for the pure rear volunteers since none was expected.
- The pure rear volunteers exhibited less vertical motion at T1 than the oblique rear volunteers, possibly because they were braced and therefore had straighter, ‘stiffer’ spines prior to impact. All T1 vertical motion was caused by the volunteers’ spines flattening against the seat back in both series of tests.
- The oblique rear volunteers loaded the seat back asymmetrically.
- Both sets of volunteers loaded the top and bottom of the seat back more than the middle (shoulders and pelvis) and the bottom of the head restraint.
- Both sets of volunteers showed muscle activation sufficiently early after the impact for their muscles to have affected their motion during impact.

RID^{3D} General Set-up and Use

The procedure for setting the neck cable tension on the RID^{3D} at present requires the dummy to be dismantled which can be very time-consuming. Unfortunately, the dummy cannot be set up prior to shipment. Once the cable tension has been set correctly, it can only be verified using a qualitative method as no quantitative method exists.

As the dummy is designed specifically for use in shaped car seats it is extremely difficult to position in a seat with a flat or abnormal shaped seat back as its back has been given a fixed, curved profile. The rigid thoracic spine and non-human-like back flesh made it impossible to put the dummy in the same seated position as the volunteers as they were able to configure themselves to the nuances of the particular seat. This is a feature that may be considered advisable in a human surrogate. The back flesh also prevented any shoulder interaction with the seat back and made the dummy unable to detect any asymmetric loading from the seat back. The difficulties in positioning the dummy also extended to setting the lumbar and T1 brackets correctly. Small differences in the settings used for these brackets (±2°) can, according to manufacturers, have a significant effect on the dummy’s response.

Although the tilt sensors were set and recorded as accurately as possible, it was found that it was impossible to have all sensors reading within the specified tolerance range with the dummy positioned in a flat backed seat. It was also found that without the moulded back of a car seat to support it, the dummy’s own movement after positioning was sufficient to move the tilt sensor readings outside of the setting up tolerance.

RID^{3D} Repeatability

The repeatability of internal sensor readings was monitored during testing to ensure that a sufficient number of tests had been conducted to identify any possible anomalies. In general, the repeatability of response was found to be good according to both internal and external sensors (Figure 6). However, there were anomalous readings recorded by both the upper and lower neck load cells as illustrated in Figure 7.

The kinematic responses indicated that the RID^{3D} responses were repeatable at 2g but there was some variation in the response at 4g (Figure 8).

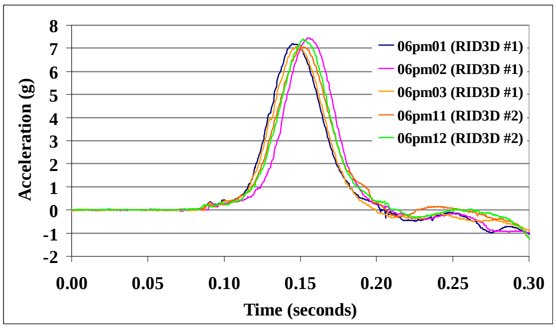


Figure 6: Head Centre of Gravity Fore-Aft Acceleration (pure rear tests at 2g)

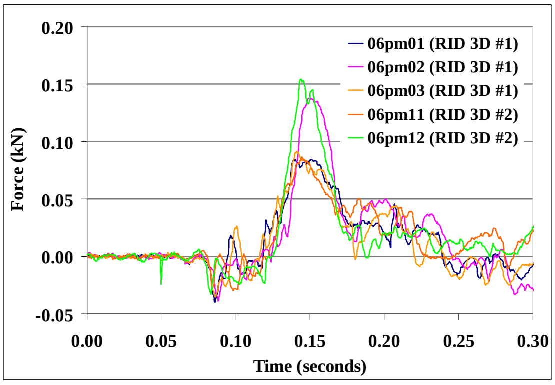


Figure 7: Upper Neck Load Cell Axial Force (pure rear tests, both dummies, at 2g)

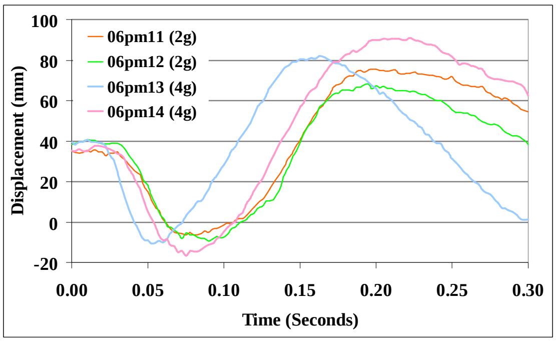


Figure 8: Head Centre of Gravity Displacement relative to T1 (pure rear, 2g and 4g tests)

RID^{3D} Reproducibility

When the internal sensor readings were compared during testing, little difference was found between the responses of the two dummies (Figure 6), although some sensor readings showed small differences in the response characteristics. However, when the kinematic responses were compared, distinct differences were found for every parameter (Figure 9 and Figure 10). These differences have been attributed to the lumbar spines of the two dummies not having been certified dynamically prior to testing. Subsequent testing has revealed differences between the two spines in terms of stiffness.

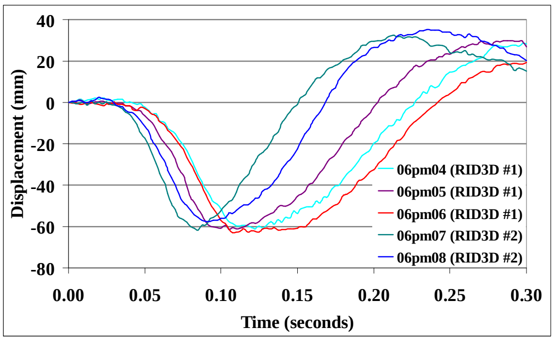


Figure 9: Head Fore-Aft Displacement relative to T1 (oblique rear tests, at 2g)

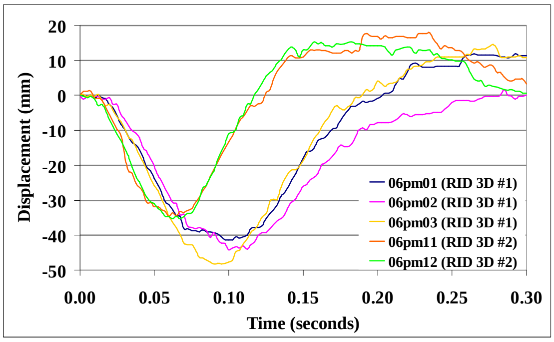


Figure 10: Chest Fore-Aft Displacement (pure rear tests, at 2g)

RID^{3D} Biofidelity

The two dummies produced very similar amounts of head and T1 fore-aft displacement as compared with the volunteers. However, the differences between the responses from the two dummies were a problem in this respect. Figure 11 shows that the response from the RID^{3D} #1 fits within the corridor, whilst the response from the RID^{3D} #2 was quite different.

The main differences between the RID^{3D} responses and those of the volunteers were in the amount of vertical motion (Figure 12) and head rotation about the z-axis (Figure 13). The RID^{3D}'s spine is too rigid to allow much head rotation about the z-axis and although it showed some ability to mimic the human vertical motion relative to the seat back this was insufficient, particularly in oblique impact where the asymmetric loading appeared to reduce the spine's flexibility.

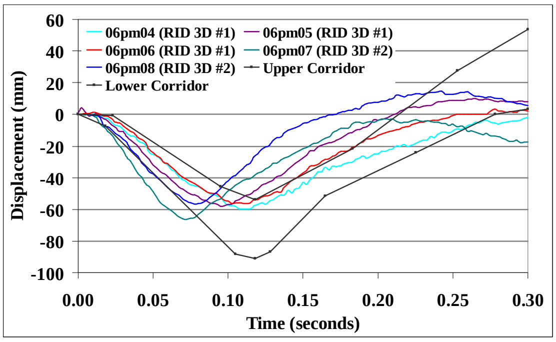


Figure 11: T1 Fore Aft Displacment relative to seat back (oblique rear tests, at 2g)

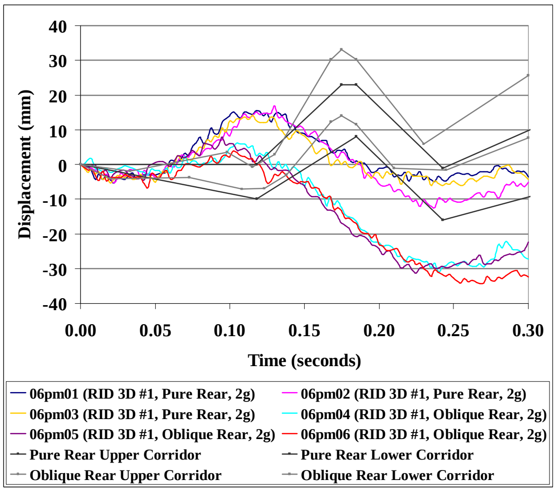


Figure 12: T1 Vertical Displacement relative to seat back (pure and oblique rear tests, at 2g

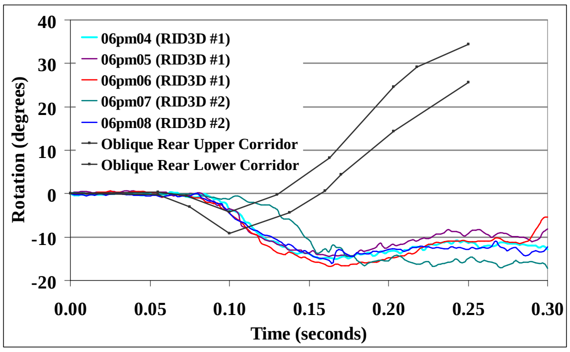


Figure 13: Head Rotation about the z-axis (oblique rear tests, at 2g)

Pressure profiles

The pressure profile readings taken during testing were compared to those taken during volunteer testing and showed that the dummies' interaction with the seat back were very different to those of the volunteers (Figure 14 and Figure 15). When the force distribution from a typical dummy test was compared to the load cell readings from the volunteer tests there were also noticeable differences in the way the dummy loaded the seat back.

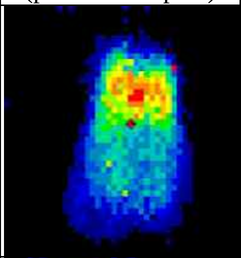
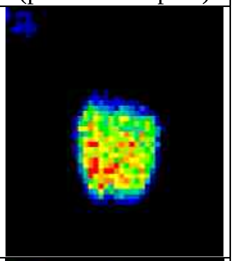
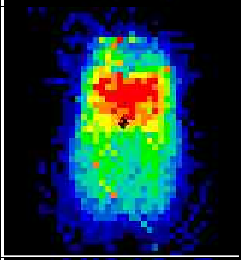
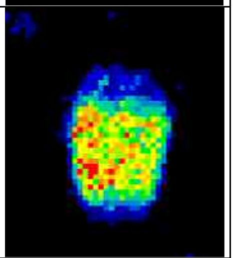
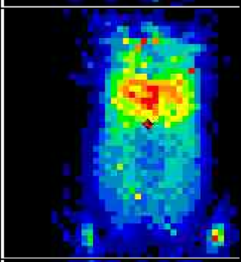
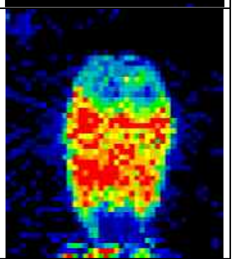
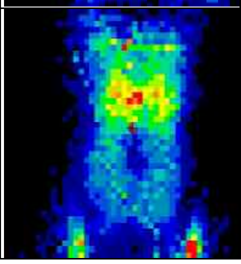
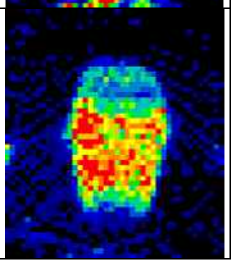
Approx. Time (ms)	Typical Volunteer (pure rear impact)	RID^{3D} (pure rear impact)
0		
30		
67		
105		

Figure 14: Comparison of pressure profiles from a typical volunteer and the RID^{3D} (pure rear tests)

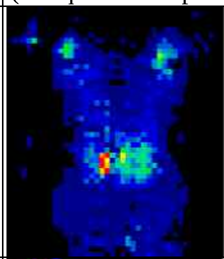
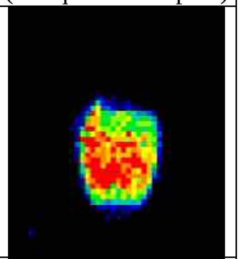
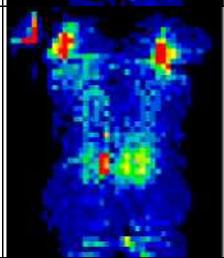
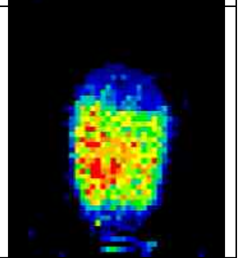
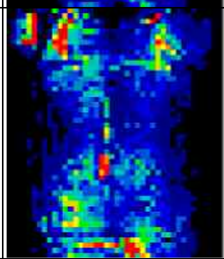
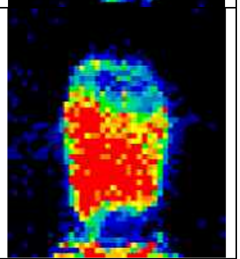
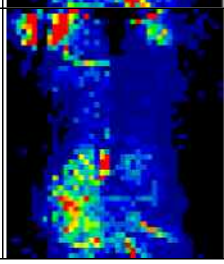
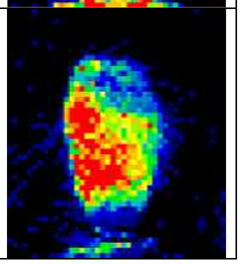
Approx. Time (ms)	Typical Volunteer (oblique rear impact)	RID^{3D} (oblique rear impact)
0		
30		
67		
105		

Figure 15: Comparison of pressure profiles from a typical volunteer and the RID^{3D} (oblique rear tests)

Comparison of RID^{3D} Response with Other Dummies in Pure Rear Impact

The BioRIDIIb, THORα and THORα with a EuroSID neck were all tested under the same pure rear impact conditions as the RID^{3D} and volunteers. (BioRID is now at version 2g and the THORα has since been developed further as the THOR-NT and the THOR-FT has also been created. Each dummy was tested at least twice under the same impact conditions. The repeatability of response was good for every dummy except the THOR with the EuroSID neck. There appeared to be a problem with the impact point (T_0) timing of the RID^{3D} results and hence they were adjusted to fit with the other dummy responses.

Considering the acceleration responses, both the BioRID and RID^{3D} produced fore-aft head and T1 responses that were very close to the volunteer responses (Figure 16). Similarly the fore-aft displacement responses for both dummies were close to or within the volunteer corridors and very similar to each other. The main differences between the dummy responses were apparent in the vertical accelerations and displacements. For the head and T1 accelerations, both the RID^{3D} and BioRID had the correct characteristics to their responses but the BioRID response was closer to the corridors (Figure 17 and Figure 18). The relative timing of the BioRID head fore-aft and vertical accelerations was also closer to that of the human volunteers than the other dummies. The THOR responses were very different to the corridors (not surprising since THOR was designed for high severity frontal impact). When head vertical displacement is considered (Figure 19) the BioRID had the best response but was still not close to the corridor; however, the RID^{3D} and THOR with EuroSID neck had much better T1 vertical displacement responses (Figure 20) with the correct characteristics compared to the corridor, although again, they were not close to the corridor in the time domain.

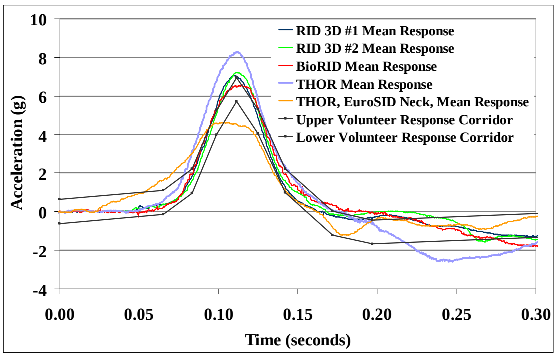


Figure 16: Head Fore-Aft Acceleration

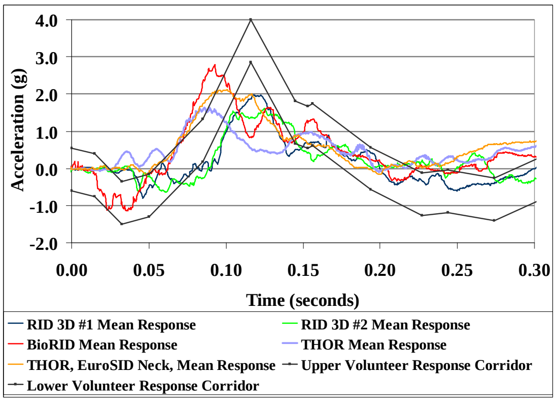


Figure 17: Head Vertical Acceleration

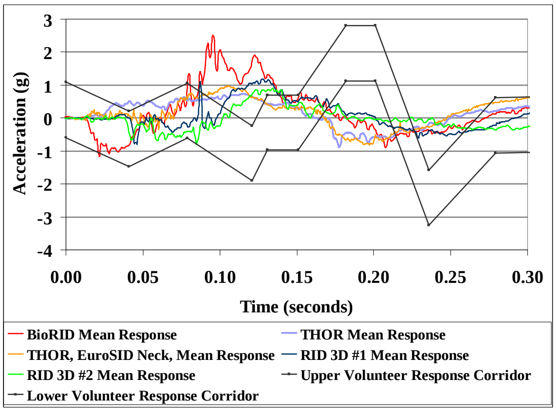


Figure 18: T1 Vertical Acceleration

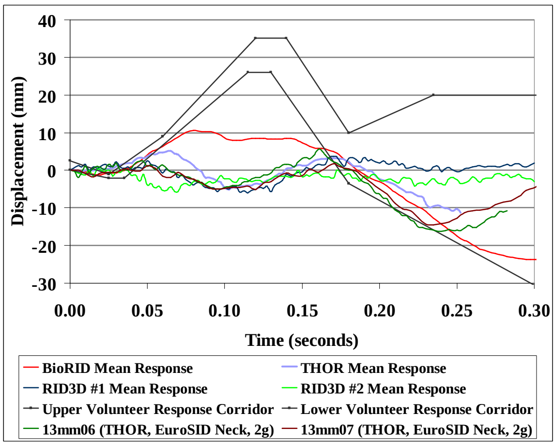


Figure 19: Head Vertical Displacement

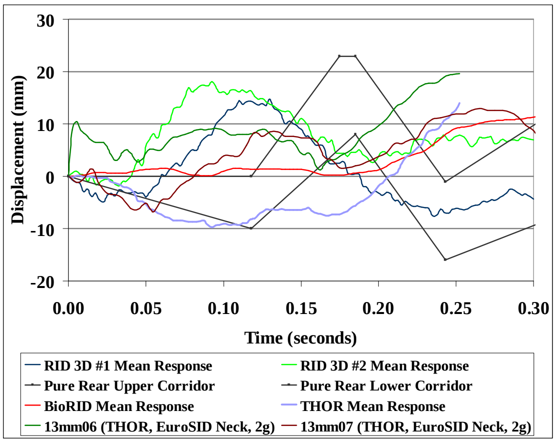


Figure 20: T1 Vertical Displacement

An unusual effect was observed when the recorded axial neck loads for each dummy were compared; the BioRID neck load cell recorded a compression peak, whilst the other dummies recorded neck tension during the same part of the impact (Figure 21. When the relative accelerations of the human head and T1 are compared from the volunteer tests, the head is accelerated upwards initially and then downwards relative to T1, causing compression in the neck itself (Figure 22); thus the BioRID response would appear to be most representative of the effects experienced by a human.

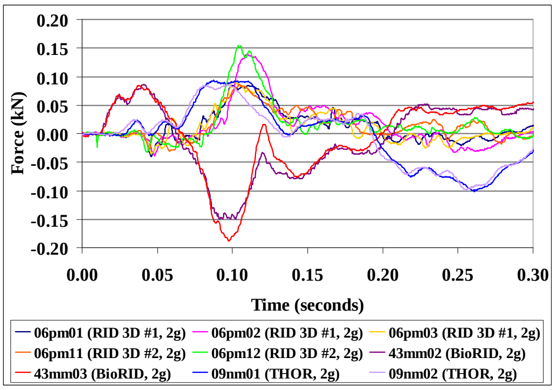


Figure 21: Comparison of Neck Axial Force recorded by each dummy

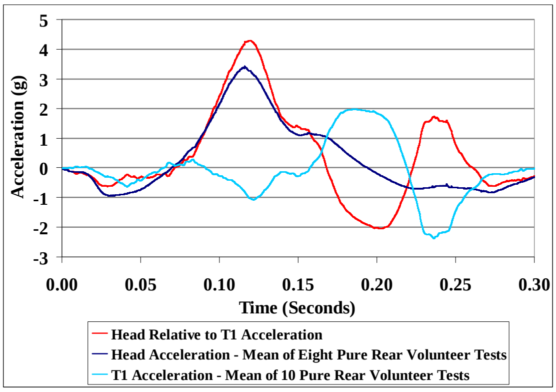


Figure 22: Relative Acceleration of Head and T1

ANALYSIS

RID^{3D} Reproducibility

The differences between the responses from the two dummies were investigated thoroughly. One of the dummies had kinematic responses closer to the volunteer corridors than the other. However, it was not known whether the RID^{3D} showing the least biofidelity was the one functioning incorrectly or correctly. To determine which response was from the faulty RID^{3D}, the tilt sensor readings and visual images for each test were compared to identify any differences in the initial positioning or set-up of the dummies that might have caused the differences in response but no explanation was found. The RID^{3D} spine consists of a flexible, straight lumbar element, two solid steel sections and a small flexible thoracic element connecting the two steel sections as illustrated in Figure 23. The lumbar elements are identical to those used in a EuroSID dummy; however, in this instance these units were not certified dynamically prior to testing. Subsequent certification tests revealed significant differences in the stiffness properties of the two elements. Unfortunately, the element which produced the most human-like kinematic response was the one which failed the certification tests because it was too stiff. It is recommended that the effects of the lumbar spine properties on RID^{3D} kinematic response be investigated further.

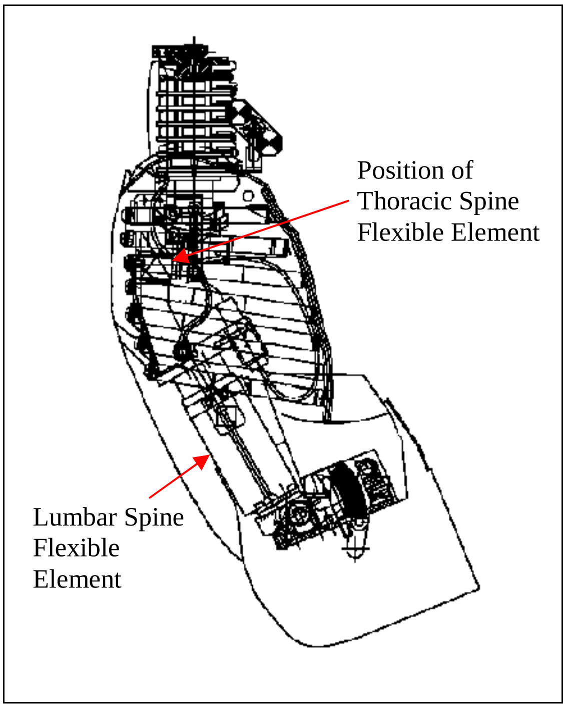


Figure 23: Schematic of the RID^{3D} Torso illustrating the position of the Lumbar and Thoracic Spine Flexible Elements

Dynamic certification criteria do not exist for the thoracic spine element. It is suggested that some of the problems identified may be attributed to this uncertified part. The interaction of the lumbar and thoracic elements, each having potentially different material properties for each dummy, could possibly explain the differences observed between the kinematic responses of the two dummies.

RID^{3D} Biofidelity

The design of the RID^{3D} spine and back flesh can also explain the lack of vertical motion in its response and the differences between the way the dummies and humans interacted with the seat back. The human volunteers initially had some degree of natural curvature in their spines prior to impact (depending on their posture and the amount of pre-impact bracing). They were then pushed backwards into the seat back by the impact. This had the effect of causing their spines to flatten against the seat back, adapting to the shape of the seat, and hence for their thoracic spines, necks and heads to move upwards. The dummies started with most sections of their spines straight prior to impact and hence any vertical head and neck motion was minimised. However, the motion recorded at T1 showed that the RID^{3D} has the correct form in its response but the response is too rapid. The amount of vertical motion is also reduced in the oblique impact – implying the RID^{3D} design is less able to produce the correct vertical motion when loaded obliquely. The head vertical motion shows that the neck design does not allow the correct relative vertical motion between T1 and head. In contrast, the BioRID shows almost no vertical motion at T1 but excellent relative motion between head and T1, including the timing of the response. It is suggested that this is due the fact that the BioRID neck starts with a natural curvature, representative of human posture. Its poor T1 vertical motion is caused by the fact that its flexible spine is designed to start with the lumbar spine straight and a natural curve in the thoracic area; this initial starting posture may have prevented there from being much spine straightening during the impact. It is possible that the thoracic spine was flattened against the seat back in its initial starting position as the resistance to bending/straightening at this section of the spine is limited.

The BioRID has the advantage of engaging with the seat back in a more human-like manner compared with the RID^{3D}. The problem with the RID^{3D}'s engagement with the seat back is that all of the load is transmitted to the seat through the back flesh, which is designed for a specific in-car posture. This prevents the dummy's shoulders and pelvis from engaging with flatter seats than the back flesh was designed for. This would prevent the dummy from "seeing" asymmetric loading or yielding caused by the seat in a test environment.

Both RID^{3D} and BioRID dummies have some limitations with regard to the biofidelity of their response and their suitability for use in a regulatory impact test procedure. However, it would seem that the most human-like dummy in terms of kinematics and forces detected would be the most suitable candidate. Currently, the BioRID's response is closer to that of a human in terms of relative head and neck motion and the forces recorded by the neck load cells. The BioRID also appears to have better seat back interaction capabilities. However, the reproducibility of the BioRID response was not determined in this test series, neither has its response been evaluated under oblique loading conditions to assess its suitability for detecting asymmetric loading. It is not known how suitable either dummy would be for detecting lumbar injuries which are also prevalent in low severity rear impacts.

DISCUSSION

At the current time, rear impact dummies are only being used in consumer type evaluations. It is suggested that for regulatory application they should be more robust and able to assess injury risk with biomechanical foundations since approval thresholds should be related to the risk of injury, rather than comparative seat performance.

In a regulatory framework it will not be known what the structure of seats will be, that the dummy will be required to assess and whether the seat will yield to absorb energy. In addition one can not guarantee that a vehicle seat would yield symmetrically or load the dummy symmetrically thus the regulatory test device must be able to 'adapt itself' to many different types of loading structure. It is also suggested that any dummy should be able to assess injury risk for 'all rear impact injuries', not only ones to a particular body segment. If all areas are not simultaneously assessed, it could be possible to transfer injury risk from one body area to another by protecting one area and not another. A holistic approach to rear impact safety is essential.

It is acknowledged that the test seat used in this study was one that would not be seen in a vehicle but was used as it was easy to define and build and can be replicated easily by other research groups. The test also attempted to evaluate whole body behaviour and not just head and neck kinematics. It is suggested that a dummy that could be used for regulatory evaluations should be able to adapt to any seat design, as did the human volunteers, and be able to assess all types of loading to ensure that whole body injury risk is reduced and not just transferred. Therefore, this 'non-car' seat test configuration is a valid assessment of dummy behaviour.

The oblique tests loaded the humans asymmetrically thus any dummy should be able to respond in like manner, since one should not expect all vehicle seats to fail symmetrically, even in a pure rear impact test. This asymmetrical loading was most evident in the shape of the pulse detected by the left and right accelerometers, externally mounted on the head of the volunteer or dummy. This indicates that for any type of regulation testing, a dummy should be fitted with a 6 or 9-axis array of head accelerometers, rather than a centrally mounted tri-axial array to allow any lateral or rotational components of the motion to be detected.

Both the RID^{3D} and BioRID dummies showed attributes that would be beneficial for a regulatory fit test dummy. It is not possible to indicate the overall importance of the results presented in this paper since the test severities were sub-injury. Therefore it is not known whether dummies that did not comply would be more or less appropriate at higher impact severities. Even so it is suggested that if a dummy could match both the pure rear and oblique rear requirements then it would be a very good candidate dummy for injury risk assessment.

Neither dummy met fully the defined requirements but both had positive and negative features. It is suggested that a hybrid of the two dummies may be the best for regulatory use.

CONCLUSIONS

RID^{3D} Repeatability and Reproducibility

When each RID^{3D} dummy response is considered in isolation, most of the acceleration and displacement responses appear to be repeatable for the tests conducted at 2g, except for the outputs from the neck load cells, which showed anomalous readings.

A significant doubt concerning reproducibility was determined in that the motion of the two dummies varied significantly for the same test set-up. The problem affected the response of the entire dummy and not just the motion of the head and neck. It is hypothesised that this could be explained by the properties of the lumbar spine elements which were subsequently found to be different, as these parts were not certified dynamically prior to testing. The set-up was sufficiently tightly controlled to be ruled out as a possible cause of the differences seen.

A comparison of the responses from the two RID^{3D} dummies, that were tested in this programme, in pure and oblique rear impact, suggests that the RID^{3D} spine may be less flexible when loaded obliquely and hence less human-like.

RID^{3D} Biofidelity

Many of the responses from RID^{3D} #1 fitted within or were close to the volunteer response corridors; the exceptions were the head and T1 vertical accelerations and displacements and the head rotation about the z-axis.

The RID^{3D}s produced less head and T1 vertical motion, particularly for oblique impact, probably due to the inability of the spine to adapt to the profile of the seat back in the same way as a human.

The z-axis rotation of the RID^{3D} spine under low severity oblique rear impact conditions is very different to that of a human; the results imply that the neck is much too stiff to allow the correct rotational response.

The RID^{3D} seat back profile is fixed completely differently to that of a human being. Currently there would be no way for the RID^{3D} to detect localised or asymmetric loading from the seat-back due to the design of the back flesh and rigidity of the spine (compared to the BioRID).

Since the RID^{3D} thoracic spine is not able to adapt to the profile of the seat back in the same way that a human would, it has implications for proper activation of active head restraints in car seats and the assessment of other spinal injury.

Comparison of RID^{3D} Responses with BioRIDIIb and THORα in Pure Rear Impact

The BioRID head and neck motion is more human-like in terms of the characteristics of the response compared with any of the other dummies tested, even though the timing is not always correct.

The RID^{3D} T1 displacement response has the most potential in terms of human-like motion characteristics compared to the other dummies tested, although some further development is suggested as the amount of vertical motion is noticeably less than that of a human.

The responses for the RID^{3D} and BioRID are similarly close to the fore-aft volunteer response corridors generated for pure rear impact. However, neither dummy fully complies with the defined corridors. It is not known which responses are most significant in terms of injury generation. Hence, it must be assumed that neither dummy is currently adequate to assess injury risk.

The THOR dummy responses were seldom as close to the corridors as those of the BioRID and the RID^{3D}, which was as expected since the THOR was not designed for rear impact.

Differences are noted between pure rear impact and oblique rear impact conditions. Since it is not known how the dummies would be loaded in a regulatory test, even if it was only a pure rear impact test, it is recommended that any dummy should comply with both the pure rear and oblique rear requirements.

FUTURE DIRECTIONS

This whole research program has developed a set of quality dummy design and assessment targets that should be used for the assessment of test dummies to be used in low severity rear impact testing, taking a holistic approach to dummy behaviour (Willis et al, 2004 [6] and Roberts et al, 2002 [7]). The different candidate dummies that could be used in a regulatory test have been evaluated, but not in all the equivalent or comparative test conditions. It would be advantageous to be able to complete the test matrix so that equivalent comparative comments could be made regarding the latest version of the dummies in the comparative tests.

Both the RID^{3D} and BioRID dummies have positive and negative features. It is suggested that dummy designs should be encouraged to merge the best features of the dummies into a single advanced test device that could be used in a regulatory test procedure.

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